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REPORTS

Measurement of the Effect of Amazon Smoke on Inhibition of Cloud Formation

Ilan Koren,[1,2]* Yoram J. Kaufman,[1] Lorraine A. Remer,[1] Jose V. Martins[1,3]

Urban air pollution and smoke from fires have been modeled to reduce cloud formation by absorbing sunlight, thereby cooling the surface and heating the atmosphere. Satellite data over the Amazon region during the biomass burning season showed that scattered cumulus cloud cover was reduced from 38% in clean conditions to 0% for heavy smoke (optical depth of 1.3). This response to the smoke radiative effect reverses the regional smoke instantaneous forcing of climate from −28 watts per square meter in cloud-free conditions to +8 watts per square meter once the reduction of cloud cover is accounted for.

The net effect of aerosols on the atmospheric radiation budget and climate constitutes the greatest uncertainty in attempts to model and predict climate (*1*). Aerosols can counteract regional greenhouse warming by reflecting solar radiation to space or by enhancing cloud reflectance (*2*) or lifetime (*3*, *4*). However, aerosol absorption of sunlight is hypothesized to slow down the hydrological cycle and influence climate in ways not matched by the greenhouse effects (*5*, *6*). During periods of heavy aerosol concentration over the Indian Ocean (*7*) and Amazon basin (*8*), for example, measurements have revealed that absorbing aerosols warmed the lowest 2 to 4 km of the atmosphere while reducing by 15% the amount of sunlight reaching the surface.

Less irradiation of the surface means less evaporation from vegetation and water bodies, and (unless the smoke is concentrated near the surface only) a more stable and drier atmosphere, and consequently less cloud formation. This effect was defined theoretically as a positive feedback to aerosol absorption of sunlight (*9*) and was termed the semi-direct effect. A similar process, defined as cloud burning by soot, in which solar heating by the aerosol reaches its maximum near the top of the boundary layer, thereby stabilizing the boundary layer and suppressing convection, has been described (*10*). These cloud simulations were based on aerosol observations of INDOEX (Indian Ocean Experiment) (*11*) and focused mainly on the amplification of daytime clearing due to aerosol heating. Reduction of evaporation from the Mediterranean Sea by pollution from northern and eastern Europe was modeled to reduce cloud formation and precipitation over the Mediterranean region (*12*), in general agreement with measurements (*13*). However, warming of the atmosphere by similar widespread pollution aerosol over southeastern China was modeled to cause uplift of the polluted air mass over an area of 10 million km^2, which then was replaced by cooler moist air from the nearby Pacific Ocean, causing an increase in precipitation and flooding that fits observations from this region in recent years (*14*).

Here, using data from the MODIS-Aqua space instrument, we report measurements of the effect of smoke on cloud formation over the Amazon basin during the dry season (August–September) of 2002—namely, the reduction of the fraction of scattered cumulus clouds with the increase in smoke column concentration.

The area is under the influence of a regional high-pressure zone above a surface boundary layer and is associated with lower precipitation, land clearing, and biomass burning. The moisture source for the cloud formation and precipitation in the region is water vapor evaporated locally through plant evapotranspiration and moisture transported from the Atlantic Ocean (*15*), each responsible for half of the moisture that falls as precipitation. Easterly winds carry the moisture from the Atlantic Ocean throughout the Amazon basin until they reach the barrier of the Andes, where they decrease in velocity and veer either north or south (*16*) (Fig. 1).

The scattered cumulus clouds (also called boundary layer clouds) emerge regularly in the morning over the eastern shore. By local

[1]NASA Goddard Space Flight Center (GSFC), Greenbelt, MD 20771, USA. [2]National Research Council, Washington, DC 20001, USA. [3]Joint Center for Earth Systems Technology, University of Maryland, Baltimore County, Baltimore, MD 21250, USA.

*To whom correspondence should be addressed. E-mail: ilank@climate.gsfc.nasa.gov